May, 1894.]

THE

TRANSACTIONS

OF THE

ROYAL IRISH ACADEMY.

Volume XXX.—Part XII.

ON THE VOLCANIC DISTRICT OF CARLINGFORD AND SLIEVE GULLION. PART I.—ON THE RELATION OF THE GRANITE TO THE GABBRO OF BARNAVAVE, CARLINGFORD.

By W. J. SOLLAS, LL.D., D.Sc., F.R.S., Professor of Geology and Mineralogy in the University of Dublin.

Plates XXVI and XXVII.

DUBLIN:
PUBLISHED AT THE ACADEMY HOUSE, 19, DAWSON-STREET.
SOLD ALSO BY
HODGES, FIGGIS, & CO., Ltd., GRAFTON-STREET.
And by WILLIAMS & NORGATE,
LONDON: 14, Henrietta-street, Covent Garden. | EDINBURGH: 20, South Frederick-street.
1894.

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XII.

ON THE VOLCANIC DISTRICT OF CARLINGFORD AND SLIEVE GULLION. PART I.—ON THE RELATION OF THE GRANITE TO THE GABBRO OF BARNAVAVE, CARLINGFORD.

By W. J. SOLLAS, LL.D., D.Sc., F.R.S., Professor of Geology and Mineralogy in the University of Dublin.

(Plates XXVI. and XXVII.)

[Read May 8, 1893.]

From the centre of the Ordovician tract of the county Down, traversed by the same meridians as the ancient volcanic islands of Mull and Skye, rise the fine mountain groups of Carlingford, Slieve Gullion, and Mourne. The remains of long-ago extinct volcanos, which were in full activity during the great mountain-building epoch of the Tertiary era—they remind us, in some degree, of the volcanos of Auvergne, particularly in so far as they are associated with a great granitic area of vastly more ancient date than themselves.

Whatever interest they have lost with their activity has been more than amply restored to them in the revelation, through the action of denudation, of their internal structure, wherein we can now trace the results of those subterranean processes which in a modern volcano lie so far removed beyond the range of observation.

My introduction to this remarkable region I owe to the kindness of my illustrious predecessor, Dr. Haughton; while to the Academy I am indebted for the assistance it has from time to time afforded me in the prosecution of my researches. The account I have now to offer is but a first instalment towards a more complete account of the district.

The first reference to the mountain of Barnavave that I have met with was made by Sir Richard Griffith (1), who, in his presidential address to the Geological Society of Dublin, in 1843, announced, with explicit clearness, the fundamental fact of the intrusion of the granite which forms the base

of the mountain into the gabbro which forms its summit. The statements of Sir Richard Griffith were confirmed by Dr. Haughton, who, in a succession of Papers communicated to the Geological Societies of London and Dublin (2, 3, 4), added greatly to our knowledge, and rendered it more exact by chemical analyses of some of the more important minerals and rocks. He also determined the age of the rocks to be post-Carboniferous, and recognising the similarity of the gabbro to that of Skye, prepared the way for the now generally accepted view which assigns them to the same petrological province as the Tertiary volcanos of the western isles of Scotland.

Dr. Haughton clearly perceived the intrusive character of the granite veins which penetrate the gabbro of Barnavave, but an idea that the gabbro might have been produced by an incorporation of some of the adjacent Carboniferous limestone with the granite led him to consider the veins of this rock as practically contemporaneous with the gabbro into which they have been injected.

The next investigator was Mr. W. Traill (5), who has faithfully represented the structure of Barnavave, both on the map of the Geological Survey and in section in the Memoir accompanying it. Notwithstanding, we find that the latest writer on the district, Professor A. von Lasaulx (6), has expressed a doubt as to the true succession of the rocks, stating that, in his opinion, the granite is probably the older of the two. Professor von Lasaulx had already rectified several important errors on the part of the author of the "Microscopical Notes" in the Survey Memoir, and it was, perhaps, a not unnatural consequence that he should suspect the infallibility of the Field Geologist also. A visit to the mountain, which, it is to be regretted, he was unable to pay, would have satisfied von Lasaulx that in this case his suspicions were misplaced.

From the geological map of the Survey, prepared by Mr. Traill, we readily learn that the gabbro (styled in the legend, "hypersthene dolerite") forms the summit and upper part of the mountain, while the lower part consists of the acid rocks, granite, and granophyre, known to the Survey as "syenite," "elvanite," and "felspar porphyry."

The junction of the granite with the overlying gabbro is extremely well

defined, and, owing to the absence of glacial drift and the contrasted characters of the two rocks, is easily followed from the southern end round the western side of the mountain. The contrast, in appearance, of the two rocks is extreme; they differ not only in colour—the granite being of a greyish, or almost white tint, and the gabbro dark, almost black—but in relief also, owing to the curiously different fashion in which they weather. The gabbro, so soon as it is disintegrated by chemical changes, is denuded by the washing away of the altered material; it constantly presents, therefore, a fresh surface to the view, and there is no difficulty in breaking from it unweathered specimens with the hammer. The disintegrated granite, or granophyre, on the contrary, remains coherent for a much longer time; so that although it weathers quite as fast, if not faster than the gabbro, it is much less rapidly washed away, and fresh specimens are comparatively difficult to obtain. As a natural consequence, dykes of granophyre stand out in bold relief from a surface of gabbro, while fragments of gabbro which have been caught up and entangled in the granophyre reveal their presence by pits, each fragment, however small, down to a millimetre or even less in diameter, having its surface well below that of the surrounding granophyre. It is this fortunate difference in the appearance of the two rocks—the gabbro, with its black intaglio, and the granophyre, with its white relief—that enables us to trace out their relations in the field with a certainty, even as to minute details that would, under less favourable circumstances, be altogether impossible.

In addition to the two great dykes represented in the map of the Geological Survey, there exists a great multitude of smaller ones, ranging from a few feet in thickness down to the fineness of writing paper. The following illustrations, from "Kodak" photographs, represent a few of the chief varieties. Dykes, with straight sides running like a wall, sometimes almost vertically, sometimes nearly horizontally, as shown in figure (Pl. XXVI., fig. 1), are somewhat exceptional; winding or zigzagging, repeatedly branching, and intersecting dykes are commoner. In many cases a breccia of gabbro fragments of very various size occurs, having the interstices completely filled with granophyre, which can be traced into connection with adjacent dykes (Pl. XXVI., figs. 2, 3, 5). In this case

the granophyre has simply filled up the cracks without greatly displacing the fragments, but in others it has dislodged the broken material and carried it along with it; indeed, so generally has this taken place that the majority of the small dykes of granophyre are crowded with material broken from the gabbro, including both fragments of the complete rock and isolated crystal constituents. These are readily recognised in the field by the pittings they produce on the weathered surface of the dyke. Under the miscroscope they afford material for a very interesting study, the results of which will be given later on.

The very thin dykes, which we may distinguish as lamellar, are remarkable, not only on account of their thinness, but also for their abundance, occurring in great numbers, often at distances of less than an inch apart they seam the gabbro through and through. They frequently run in parallel lines, forming groups, and when, as is not unusual, one group cuts across another, approximately at right angles, they produce on the surface of the gabbro the rude kind of cross-hatching represented in figure 7, Pl. XXVI. Such intersecting groups forcibly recall the conjugate systems of joints so often produced by crust stresses, and such joints, now injected with granophyric material, they, in all probability, represent.

But the injection of granophyric material did not terminate with the filling of these joints. I have before me a remarkable specimen of the lustrous black gabbro of Barnavave, which is splashed in a very artistic fashion with irregular white patches, varying from a centimetre to less than a millimetre in diameter (Pl. XXVII., fig. 17). They are produced by little knots of quartz and orthoclase, with an occasional flake of green mica, and might readily be mistaken for original constituents of the rock, or as representing the residual mother liquor, which was left to crystallize out in the last stages of consolidation of the gabbro. The apparently complete isolation of many of the knots, in the midst of the surrounding gabbro, might be claimed as confirming such a view. It does not require, however, a very profound investigation to convince us of their true nature; thin threads of granophyre can be discerned extending from them, and these can frequently be traced into connection with a lamellar dyke, on which, indeed, many of the knots are directly seated. The lamellar

dyke in my hand-specimen can be traced continuously from the knots into connection with a larger dyke, half an inch in thickness, and this I followed in the field into connection with one of still larger dimensions, which was continued downwards into the great underlying granitic mass.

The granophyric patches evidently occupy the place of drusy cavities which, subsequent to their formation, were cut across by narrow cracks or joints; through these joints the liquid granophyre found a path to the druses, which it reached and filled; but even in these minute cavities the granophyre had not reached its confines, for from them and from the lamellar dykes the finest visible granophyric processes are continued into cracks in the constituent crystals of the gabbro—cracks so fine that they can only be traced with the aid of the microscope, so penetrating was the action of the granophyre, and so intimate is the mixture it has produced.

We are now in a position to make the following summary statements:—

1. *The gabbro of the Carlingford district is older than the granite which penetrates it.*

This is proved (1) by the occurrence of granophyre dykes in the gabbro, and the absence of gabbro dykes in the granophyre; (2) by the presence of included fragments of gabbro in the granophyre and the absence of included fragments of granophyre in the gabbro; (3) by the presence of a lithoidal selvage to many of the granophyric dykes, and the absence of such a selvage from the gabbro.

2. *The gabbro was already completely solid, traversed by contraction joints, and, probably, fractured by earth movements before the injection of granophyric material.*

3. *The granophyric material was in a state of great fluidity at the time of its intrusion.*

This is shown by the remarkable manner in which it finds its way into the minutest cracks and cavities. That it was not, as it has been expressed, in a state of "porridge," is proved by the occurrence of crystals of quartz and felspar in the now filled up druses, having greater dimensions in

every direction than the width of the communicating lamellar dykes. From this it is evident that the formation of crystals within the druses must have taken place after the infilling.

4. *The granophyric dykes are in no case "contemporary veins."*

Many of the dykes have the appearance of basic rocks, a fact which deeply impressed Dr. Haughton and Mr. Traill, but this results from the large quantity of basic material which was supplied to them in a solid state by the gabbro. Had the two kinds of rock been less dissimilar in appearance than they are, there can be little doubt that the lamellar dykes would have been generally acknowledged to be good examples of "contemporary veins." As it is, the sharp and well-defined junctions of the rock, as seen in the field, and the evidence we shall adduce from microscopical examination, render any such explanation absolutely untenable.

Although we are only treating here of the granite and gabbro, it may prevent misconception to add, that the latest eruptions in the district appear to have been basaltic. Dykes of olivine basalt may be found penetrating the granophyre, and filling in its minute drusy interstices. These basalt dykes show a characteristic tachylite selvage at their junction with the granophyre.

MICROSCOPICAL INVESTIGATION.

1. *The Gabbro.*

This is a dark-coloured, almost black rock, and thus differs from the eucrite of Slieve Foy, which is of a greyish, or greenish-white tint. In texture the gabbro is coarsely crystalline, the individuals of felspar and pyroxene frequently attaining a length of from 10 to 15 millimetres. The felspar occurs in large patches, composed of one or more individuals, which rarely present idiomorphic outlines; exceptionally, an almost complete crystal may be observed embedded in diallage. The banding due to synthetic twinning varies in coarseness; that on the albite plan, which is the commonest, usually gives rise to broad bands such as are commonly seen in labradorite and anorthite; pericline twinning is sometimes seen, and Carlsbad twins occur frequently. Sometimes a portion of a crystal

is entirely devoid of any appearance of twinning. Well-marked zonal structure is rare, but it is not uncommon to find a slight difference between the angle of extinction of the central part and of the margin of a crystal: that of the centre is always the larger.

The dark colour of the crystals is due to a very fine, almost ultra-microscopic, dust, which is generally evenly disseminated, though sometimes it is more densely distributed in some places than others, and may occasionally be altogether absent. It may be traced into granules of a larger size, which are black and opaque, and which may be safely set down as magnetite. These larger granules, unlike the fine dust, are never evenly distributed, but run along planes, which are usually planes of fracture, having no obvious connection with crystal structure. In similar cracks are found spherical and ellipsoidal granules, cylindrical rods with rounded ends and lobate bodies of quite irregular form, which are transparent, with a comparatively high refraction index, a faintly bluish colour, and no apparent structure; these are, evidently, some kind of pyroxene, and since they frequently contain or lie adjacent to a granule of magnetite, may be regarded as vestigial residues resulting from the corrosion of previously existing diallage or hypersthene. This view is supported by the fact that they may sometimes be traced into the vicinity of comparatively large corroded fragments of pyroxene, having precisely similar optical properties to those they themselves present. In some rare cases rounded threads of pyroxene traverse the felspar; they do not appear to be simultaneous growths, but must be regarded, like the scattered granules, as remnants of absorbed crystals. The well known included rods and plates of a metallic lustre, running parallel to the crystallographic axes of the felspar are occasionally very perfectly developed.

The maximum angle of extinction measured on each side of the twinning trace may reach or exceed 37°, the specific gravity is about 2·72, so that the predominant felspar may be regarded as anorthite. With the flame-test, however, it gives abundant indications of soda, and decomposes only slowly in hydrochloric acid, so that in strict phraseology it should perhaps be termed bytownite. The felspar has not been analyzed: it scarcely seemed to require it, especially as we are able to give the

results of two analyses of the closely related felspar of the eucrite of Slieve Foy; that in the first column is by Dr. Haughton, that in the second by myself.

COMPOSITION OF THE FELSPAR IN THE EUCRITE OF SLIEVE FOY, CARLINGFORD.

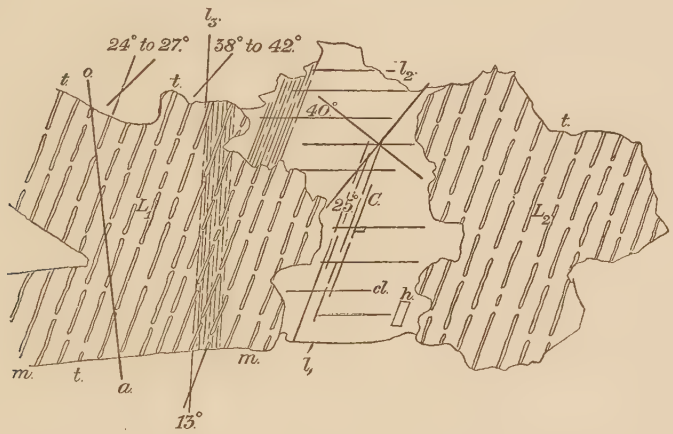
	I.	II.
Silica,	45·87	47·7
Alumina,	34·73	33·4
Ferric oxide,	—	1·3
Lime,	17·10	16·1
Magnesia,	1·55	—
Soda,	—	2.35
Potash,	—	0·62
	99·25	101·47
Specific gravity,		2·723

The second analysis, which is certainly not above reproach, corresponds fairly well with the formula An_7Ab, and evidently represents a member of the bytownite series. The species is not, however, constant in character in different portions of the rock. In some cases, as near a granophyre dyke, I have found the felspar to possess a specific gravity of only 2·705.

The pyroxenic constituents of the gabbro are hypersthene and diallage; they occur, as is usual in gabbro, in large plates lying between the felspar crystals, generally without idiomorphic outlines. In thin slices the hypersthene is almost colourless, or of a faint brown tint, with the usual pleochroism. Its specific gravity is higher than 3·34. Besides lamellar interpositions of diallage parallel to the face 100, a remarkable thread-like penetration of diallage into the hypersthene is frequently to be observed (Pl. XXVI., fig. 4). The threads are round irregular, or rhombic in transverse section (Pl. XXVI., fig. 6), variable in thickness, swelling and contracting at irregular intervals; they preserve a marked parallelism over considerable areas, but are sometimes liable to wander out of a straight path, so that a thread which presents a longitudinal section for the greater part of its course exchanges this for a transverse one before it reaches its termination. The fact that the threads extinguish simultaneously with an

adjacent crystal of diallage would alone suggest their true nature, but in addition, it is sometimes possible to trace them continuously from the hypersthene into the diallage.

In the instance selected for illustration (Pl. XXVI., fig. 4), the relations of two interpenetrating crystals of hypersthene and diallage will be rendered clear by the following diagram:—The central crystal (C) consists of diallage; on each side of it, and meeting it along very irregular boundaries, are the lateral portions (L_1 and L_2) of a crystal of hypersthene. The threads (t t), traversing the hypersthene in parallel rows, are in optical continuity with the diallage (C). Two groups of lamellar inclusions of hypersthene, accompanied by rods of magnetite, traverse the



section C, making an angle of 73° with each other; the crystal extinguishes at from 25° to 27° with the group 1_1, and at from 39° to 42° with the other group 1_2, hence it is cut approximately parallel to the face 010, and the inclusions 1_1 run approximately parallel to the axis x, and the inclusions l_2 approximately parallel to the axis z. The lateral sections L_1 and L_2 give low grey tints between crossed nicols, and are cut nearly at right angles to an optic axis, the trace of the optic axial plane being given by the line o a, which is inclined to the direction of the lamellar inclusions (l_3) at an angle of about 6°; the threads t which transverse them continue the direction of the lamellar inclusions (l_1) of the crystal C, making an angle of from 13° to 18° with the lamellar inclusions (l_3); these extinguish at a large

angle to their own length; it is difficult to determine the amount within several degrees, but it is included between 38° and 42°. The lamellar inclusions (l_3) can frequently be traced into continuity with the threads (t), and occasionally a thread deviates from its own direction to assume that of a lamella. The margin *mm* of the hypersthene appears to be idiomorphic, and makes an angle of 71° with the threads. Inclusions (h) of the hypersthene, rhomboidal in section, occur within the diallage, their edges coinciding with the directions of the two sets of lamellæ (l_1 and l_2) of their host.

From these observations it would appear that the section through the hypersthene must lie in the zone [001, 100], and since only one set of cleavage planes, parallel, namely, with the lamellæ (l_3), are visible, it cannot lie even approximately parallel with the face 001, but must approach coincidence with 100. The section of diallage which lies in the same plane as that of the hypersthene, was found, however, to lie nearly parallel with the face 010, and it is apparent, consequently, that the two species of pyroxene are so twinned that the 010 face of the one lies parallel to the 100 face of the other. This is consistent with the fact that the lamellar inclusions (l_2) of the diallage are directed approximately at right angles to the lamellar inclusions (l_3) of the hypersthene. The threads of diallage evidently lie in the 100 plane of the hypersthene, and make an angle of about 20° with the trace of the optic axial plane.

The diallage, beyond its thread-like intergrowth, presents no unusual characters; its specific gravity is over 3·34. In this, as in other respects, it closely resembles the hypersthene, from which it can easily be distinguished by its optical characters. Perhaps the tendency of the hypersthene to partial alteration into bastite may constitute an additional distinction.

In addition to the minerals already described a small quantity of apatite contributes to the composition of the rock, but I have not met with any other minerals; olivine, for instance, is not present.

2. *Granophyric Gabbro.*

The occurrence of white patches of granophyre irregularly distributed through the black gabbro has already been mentioned, and it only remains to describe their characters more minutely. The gabbro presents its usual structure, consisting of grains of bytownite, often as much as a centimetre in length, and correspondingly large grains of pyroxene; the granophyre either forms ganglionic patches up to a centimetre in diameter, or simply fills up the angular interspaces left between adjacent grains of the gabbro. Many of the granophyric areas appear quite isolated in the midst of the gabbro, but some can be directly traced into communication with a thin granophyric dyke (Pl. XXVII., fig. 17), and there can be little doubt that the isolation of the others is merely apparent, a plexus of microscopic veinlets, the existence of which can be demonstrated, bringing them all finally into communication. Under the microscope the white areas present the same microgranitic character as the associated dykes, the orthoclase felspar indicating a tendency to idiomorphic outlines, and the quartz occurring in grains of from 0·1 to 0·5 mm. in diameter, either separately or in mosaics. The quartz contains numerous vapour and liquid cavities, some of them irregular in outline, others rounded, and others, again, with a tendency to form negative crystals; many are of large size, from 0·02 to 0·05 mm. in diameter, and they frequently contain a large bubble which, in a negative crystal, may fill the whole cavity, with the exception of the rhombohedral terminations. The quartz can be traced into cracks in the adjacent bytownite of not more than 0·01 mm. in diameter. Where the bytownite of the gabbro lies in contact with the granophyre it generally loses its fine granular appearance and associated brown tint, and becomes quite colourless and transparent, at the same time it retains its characteristic synthetic twinning. The pyroxene also loses its colour under the same circumstances, and becomes more transparent; the change in the appearance of both minerals is accompanied by the excretion of magnetite. The granophyre contains a few grains of magnetite, but mica is rare, or absent.

The somewhat coarse texture of the granophyric material is of interest,

as showing that this character cannot be always relied on as an indication of the circumstances under which the rock may have cooled, and thus the objection raised by Dr. Irving to the views of Dr. Callaway with regard to the relations of the granite veins and diorite of the Malvern Hills loses its force. Dr. Callaway believes that the granite has been injected into the diorite, as I should think is more than probably the case; certainly, "the very significant fact," adduced by Dr. Irving,* "that the quartzose felspathic veins, even when less than an inch in thickness, have a coarsely-granular texture, . . . [and thus] make it impossible to believe that they crystallized in contact with a colder rock after injection into it," does not seem to me to carry such a weight of meaning; and the asserted absence of very evident dykes of granite in the diorite may very well find an explanation in the shearing which the igneous complex has undergone.

3. *Granophyre Gabbro of other Localities.*

If we turn to the fine work on "British Petrography," by Mr. Teall, we shall find described there several instances in which granophyric patches are shown to occur within highly basic rocks, such as gabbro, in very much the same manner as they do in the gabbro of Barnavave. Such acid patches have, however, hitherto been regarded by Mr. Teall and others as representing the residual mother liquor of the magma from which the more basic constituents had previously crystallized out. But since our observations have proved that in at least one known instance a different, and as I think simpler, explanation of these patches obtains, it becomes incumbent on observers to determine whether the same explanation is or is not applicable to other known cases of an apparently similar nature. The case of the enstatite-diorite of Penmaenmawr may be first cited. This rock consists of enstatite, diallage, augite, biotite, plagioclase felspar, apatite, and iron ores, while patches of granophyre occur in it, in a manner forcibly recalling those in the gabbro of Barnavave, and the presumption would naturally seem to be that they have been introduced from without

* "The Malvern Crystallines," by the Rev. A. Irving, D.Sc., Geological Magazine, 1892, p. 453.

by a process of injection—a presumption which would be greatly strengthened were we to find granophyric dykes occurring in conjunction with the patches. Fortunately, direct evidence exists on this point, for Mr. Teall describes granophyric veins as traversing the gabbro, and expressly compares them with the augite granophyres of Barnavave. Mr. Waller, who has described these veins, regards them as "contemporaneous," but this was before our observations had been made at Barnavave. I must confess, on my own part, to some difficulty in understanding what is exactly meant by "contemporaneous" vein—the expression sounds remarkably like a contradiction in terms—and as I have never yet seen a contemporaneous vein, I may perhaps be pardoned for feeling somewhat sceptical as to the existence of such a phenomenon.

Our next instance is taken from the English lake district, where a gabbro, described by Mr. Teall as containing quartz among its original constituents, occurs at Carrock Fell. This rock also is said to exist in "intimate association with an acid augitic granophyre," into which "it passes by insensible gradations." Mr. Teall kindly sent me a thin slice of this gabbro for examination, and to my eyes the relation of the quartz to the other constituents was quite compatible with the view which would regard it as having been introduced subsequently to the consolidation of the gabbro, by injection from a granophyric dyke. Till, therefore, additional evidence is produced I should be inclined to consider the gabbro and granophyre of Carrock as being related to one another in the same manner as are the similar rocks of Barnavave.

The last instance is from the Whin Sill, a dyke of enstatite dolerite, which has been investigated in a masterly manner by Mr. Teall, who describes "micropegmatite" as "playing the role of interstitial matter, exactly as it does in the more acid gabbros of Carrock Fell." The only observation I would make as regards this case is, that till minute veins or dykes of granophyre have been specially searched for in this dyke without success, it will be impossible, in the light of our recent observations, not to feel some suspicion as to the real nature of the granophyric inclusions. Not for a moment would I be thought to assert that the granophyric inclusions, in this case and that of Carrock Fell, might not have been produced

as the last stages of the consolidation of an igneous magma; all that I maintain is, that as yet we have no convincing evidence that this has actually been the case, and I await, with interest, the results of the investigations that are in progress as regards the history of one of these cases, viz. that of Carrock Fell, which is in the able hands of Messrs. Marr and Harker.

4. *The Granite.*

The main mass of the acidic rock is a somewhat reddish, or greyish white, coarsely crystallized rock, composed chiefly of a flesh-coloured felspar and colourless quartz, with occasional flakes of greenish mica. It is more or less drusy throughout its mass, and in places cavities several inches in diameter appear in it; in the space afforded by these the mineral constituents, but chiefly the quartz and felspar, have acquired a definite crystal form, the faces usually presented by the felspar being 110, 010, and 001. In this, as in its other characters, the rock closely resembles the granite of the Mourne Mountains. Under the microscope the predominant felspar is frequently found to present a cryptoperthitic structure, due to the intergrowth of orthoclase and albite. Occasionally individual crystals of albite are met with; the quartz occurs in irregular rounded grains, with a manifest tendency to pegmatitic growth; the green and brown mica is generally highly corroded; associated with it are grains of excreted magnetite and sphene. Vapour and liquid cavities, often of considerable size, are common in the quartz; they generally show a bubble, and sometimes a cubical crystal, probably of sodium chloride. Zircons are sparingly scattered through the rock.

The granite is itself traversed by dykes of various dimensions down to some of paper thinness (0·09 mm. across). These would, probably, be regarded by many as "contemporaneous," but unless this term is used in a very loose sense it cannot be accepted as applicable here: these dykes are as truly intrusive into the granite as the granite is into the gabbro. In mineral composition the dykes do not differ greatly from the granite itself, but they are much finer in grain, the constituent individuals of quartz and felspar measuring only about 0·1 mm. in diameter, while in the granite they vary from 0·5 up to and over 3 mm. Frequently also

they assume a granophyric structure: and mica is rare or absent; grains of magnetite, however, which may be taken to indicate the original presence of this mineral, are not uncommon.

At their margin these dykes frequently present an interesting modification of structure, the quartz, with intervening felspar, occurring in irregular fibres, which are directed with their long axes pointing at right angles to the bounding surface, where they are in contact with the granite (Pl. XXVII., fig. 18). The thickness of this layer, distinguished by its parallel pegmatitic structure, varies from 0·1 to 0·3 mm. Were it to occur as the lining of a small cavity, say 1 mm. in diameter, the structure could scarcely be otherwise regarded than as coarsely spherulitic. Occasionally a thin layer, about 1 mm. thick, intervenes between the parallel micropegmatite and the inclosing granite; it is distinguished by a kind of felsitic structure, its constituent grains of quartz and felspar measuring about 0·01 mm. in diameter.

From the study of these dykes I can arrive at no other conclusion than that they were intruded into the granite at a period subsequent to its consolidation; if they represent, as some would have it, the residual mother liquor, from which the granite had already crystallized out, then this mother liquor occupied a position below the granite at the time of its intrusion.

The following analyses by Dr. Haughton give the composition of the granite (I.) of Slieve-na-gloch, and (II.) of the Mourne Mountains. The granite of Barnavave is so similar in its general character that it has not been thought necessary to analyse it:—

	I.	II.
Silica,	70·48	75·00
Alumina,	14·24	13·24
Ferric oxide,	3·72	2·52
Lime,	1·48	·69
Magnesia,	0·40	—
Potash,	4·26	4·33
Soda,	3·66	3·07
Loss,	1·59	·8
	99·83	99·65

5. *The Granophyre Dykes.*

The dykes which proceed from the underlying granite into the gabbro vary greatly in texture: some are granite of fairly coarse grain, but with a decided tendency on the part of the individual constituents towards idiomorphic outlines; others, in their exquisite micropegmatitic structure, make a nearer approach to granophyre, though they seldom present the radiopegmatitic character which the definition of this rock by Rosenbusch seems to require; others, again, and these are the finest in texture, consist of very minute grains of quartz and orthoclase, showing very little of pegmatitic intergrowth. The differences which distinguish the structure of the different varieties of rock found in the dykes are to a great extent the result of different rates of cooling, and it will be convenient, though the phraseology may not be exact to comprehend them all under the term granophyre.

According to the nature of the predominant ferro-magnesian ingredient, the granophyres may be classified as follows:—

I. Biotite granophyre.
II. Biotite amphibole granophyre.
III. Augite granophyre.
IV. Diallage amphibole augite granophyre.

The list is set out somewhat fully (though not as fully as it might be), in imitation of those authors who desire to show how great a variety of rocks may be produced by the differentiation of an originally homogeneous igneous magma. Whether such an homogeneous magma anywhere exists at the present time, or has existed during the period of stratigraphical history, I know not. This does not now concern us; but certainly, as far as regards differentiation, the rocks of our list afford no illustration of it: on the contrary, they are all products of the admixture, not of magmas, but of an already solidified basic rock, with a molten acid one.

Before proceeding to a description of the varieties of granophyre it will be convenient to consider the changes which have been produced in the included fragments of gabbro and the included crystals of pyroxene and plagioclase which they contain.

6. *Transformation of the Diallage.*

The change which this mineral has undergone, and the new minerals to which it has given rise, under the influence of the granophyre, can be plainly studied along the line of junction where the granophyre meets the gabbro, as well as in the crystals which have separated from the gabbro and become immersed in the granophyre. The immersed crystals have so much the appearance of phenocrysts* that they would indubitably be mistaken for them by a petrologist who was unaware of their true nature. As a distinctive appellation appropriate to the crystals, both of pyroxene and of plagioclase felspar, which have found their way from the gabbro into the granophyre, the term "xenocrysts" may be employed. Correspondingly included fragments of the whole rock may be called "xenoliths."

Three different cases of alteration are to be distinguished—in the first the earliest signs of alteration manifested by the diallage are an increase in transparency, accompanied by the assumption of a chloritic green colour, and the excretion of magnetite; in the next, and perhaps the commonest stage, all trace of colour has disappeared, and the crystal begins to break up into numerous granules, which present a striking resemblance to the augite grains of basalt. This kind of alteration can be especially well traced in the xenocrysts, every gradation being preserved from the unaltered diallage through clusters of augite granules that mark the site of a vanished xenocryst (Pl. XXVII., fig. 12), up to dispersed granules evenly disseminated among the other constituents of the rock (Pl. XXVII., fig. 11).

In the second case the alteration is of a wholly different nature, leading to the formation of biotite. In junction specimens the first commencement of the process is indicated by the appearance of laminæ of yellowish or reddish brown biotite between the prismatic cleavage planes, or parallel to the orthopinacoidal twinning planes of the diallage. In the xenocrysts the change can be followed to its completion; in some cases a moiety of a still

* I adopt the term "phenocryst" since it has come into somewhat general use, and has the advantage of brevity; but it is a sad barbarism, "pheno" should, of course, be "phanero," and "cryst" should be "crystal." Even a barbarism seems preferable, however, to so unwieldy a term as "phanero crystal."

recognisable xenocryst of diallage may be seen lying side by side with a crystal of biotite to which it has given rise, and into which it extends in corroded apophyses; in other cases the diallage, as an individual xenocryst, has disappeared, only a few minute fragments of it remaining immersed in the biotite which has replaced it. Associated with these are other crystals of biotite, in general character precisely similar, but entirely devoid of diallage residues.

In the third case the product of alteration is hornblende; in junction specimens uralitisation is met with (Pl. XXVII., fig. 13), but in xenocrysts this has not been observed; in their case the diallage directly passes into a sage green hornblende. The hornblende first appears on the margin, forming a broader or narrower border, which increases in width till the replacement is complete (Pl. XXVI., fig. 8; Pl. XXVII., fig. 14). The resulting crystals of hornblende usually contain grains of magnetite, and are often completely riddled with quartz. Crystals of basaltic brown hornblende occur evenly scattered through some of the granophyre, and might easily be mistaken for original constituents; the presence of associated xenocrysts of labradorite, and the total absence of xenocrysts of pyroxene would, however, naturally lead one to suspect their true nature, and the occurrence of a central striated area within some of the larger hornblende crystals would put the question beyond doubt were it not for the parallel extinction of this striated portion. The striated central area resembles so closely, however, the kernel of diallage which is found within the green hornblende, undoubtedly an alteration product, that it can hardly have differed greatly in nature, and may be regarded as a residue of hypersthene, of which, otherwise, instances among the xenocrysts are rare.

Whatever kind of alteration the diallage undergoes the excretion of magnetite is a constant concomitant, and in some instances it would appear to form the greater part of the alteration products, occurring in dense glomeruli of small grains, amidst which grains of quartz and colourless augite can be recognised (Pl. XXVII., fig. 16). In such cases there can evidently have been but slight movement in the granophyre during the alteration of the diallage, or the glomeruli would have been broken up and the constituent grains dispersed. When such movement has occurred,

the grains of magnetite, as well as those of augite, are found scattered through the granophyre, much in the same fashion as the same minerals characteristically occur in basalt.

7. *Alteration of the Bytownite.*

The xenocrysts of bytownite, easily recognisable, even without the aid of polarised light, by reason of their finely granular or dusty appearance, are frequently broken and traversed with cracks, which have been injected with orthoclase, or with this mineral and quartz. They generally present a marked zonal structure, much more commonly than the bytownite as it occurs in the parent gabbro; the zones are not sharply defined in successive shells, but fade gradually one into the other; notwithstanding this, they differ widely in their angle of extinction, those at the margin extinguishing at an angle of from 10° to 15° less than those in the centre. The xenocrysts offer evidence of having undergone extreme corrosion, and their growth has sometimes been completed by an envelope of orthoclase (Pl. XXVII., fig. 15).

This diminution of the extinction angle is accompanied by the disappearance of the included dust and rods of magnetite, so that the outer zones are frequently distinguished from the inner by their clearness and transparency.

8. *Xenoliths of Gabbro.*

In some specimens of the granophyre basic patches of a dark, almost black colour occur, scattered here and there; they are frequently over an inch in diameter, and present the appearance of basalt, with which, indeed, they agree in structure and mineral composition. They consist of grains of colourless augite, some biotite, octahedra of magnetite, and lath-shaped crystals of plagioclase, intersertal in character. It is difficult to determine the angle of extinction of the felspar, because, on rotating it between crossed nicols the dark shadow passes continuously across the crystal from one side to the other through the zero point. When I first made the acquaintance of these patches, after a hasty day in the field, I was greatly puzzled by

them; and though, according to the fashion of the time, my thoughts naturally turned towards differentiation products, I could not see how, in this direction, an explanation could be found. After the observations already recorded all difficulty seems to disappear; they are not differentiation but alteration products, resulting from the action of the granophyre on fragments of gabbro which it has caught up and included. Evidence of this is to be found in the presence of phenocrysts of diallage and dusty plagioclase which lie here and there amongst the other constituents of the basic mass, the diallage passing at its margins into colourless grains of basaltic augite.

The alteration products of the diallage included in the granophyre containing these basaltic patches are colourless augite; in those granophyres in which the diallage has given birth to hornblende, basic patches also occur, but they are not basaltic; in correspondence with the nature of the replacement which has occurred in the diallage of the surrounding granophyre, the ferro-magnesian constituent of these inclusions is hornblende.

DESCRIPTION OF THE DIFFERENT VARIETIES OF GRANOPHYRE.

Biotite Granophyre.—Specimen 1. This, taken from a dyke 4 inches in width, is a fine-grained, cream-coloured rock, with patches of coarser texture, showing evident crystals of quartz and felspar: it manifests a tendency to become drusy in the coarser parts. Specks of black mica occur sparingly. Under the microscope it presents a somewhat coarse micropegmatitic intergrowth of quartz and felspar, in which are set large crystals of felspar and grains of quartz, both separate and in mosaics; the felspar consists of orthoclase, more or less intergrown with albite; it frequently presents twins of the Carlsbad type, sometimes measuring as much as 8 mm. in length; it is dusty, and contains residual fragments of corroded biotite. A curious streaky appearance is common in this, as in all the orthoclase of the dykes, suggestive of cryptoperthite, but as extinction is uniform over the whole crystal the appearance is deceptive. The quartz grains, on an average about 2 mm. in diameter, also contain biotite

residues. Crystals of zircon and grains of magnetite are generally dispersed.

This rock scarcely differs in general character from the main mass of underlying granite.

Specimen 2.—This is from a thin dyke about 2 inches wide; it is a very fine-grained felsitic-looking cream-coloured rock, with minute specks of green mica. Under the microscope it is seen to consist of angular grains of quartz and orthoclase, which show a strong tendency to idiomorphic outlines; the average diameter of the constituent grains and crystals is about 0·12 mm. Here and there patches of exquisite micropegmatitic intergrowths occur. The biotite is intensely dichroic, much corroded, and accompanied by excreted magnetite and sphene.

Biotite-amphibole Granophyre.—Specimen 3. This remarkably interesting fragment is not from Barnavave but Slieve Gullion; it was collected some years ago, and I have no notes describing its relations to the surrounding rocks. In colour it is dark grey, with scattered black specks. The microscope shows it to possess a well-developed micropegmatitic structure; the felspar is a dusty, streaky orthoclase, the quartz water-clear, with numerous liquid and vapour cavities, sometimes having the form of negative crystals; minute crystal grains also occur in it. The ferro-magnesian minerals are a green amphibole, often penetrated by quartz, and presenting the following pleochroism:—

α, honey-yellow; β, olive-green; γ, dark green;

and a brown biotite which, like the amphibole, is of remarkably fresh appearance, with the following pleochroism:—

α, pale straw-yellow; β and γ, dark reddish-brown.

It sometimes contains magnetite, which has the appearance of being an original constituent, the more so as it occasionally shows projecting from its side a large crystal of zircon, which must obviously either be seated upon the magnetite, or lie partly embedded in it. The biotite is sometimes seen sending veins into the hornblende, producing the impression that the latter mineral is the older of the two.

The rock we have so far described is a good example of a biotite amphibole granophyre; and were our observations to cease here, there would be no more to be said. A searching investigation, however, brings to light the fact that in rare instances the amphibole contains a kernel of pyroxene, extinguishing at 39° to 40°, and precisely resembling the kernals of altered xenocrysts of diallage. Similar kernels of pyroxene occur within a similar amphibole in the dykes of Barnavave. In one case a core of the altered diallage was observed, surrounded by the olive green amphibole, this, again, bordered by biotite. Furthermore, crystals of plagioclase, distinguished by their clear appearance from the dusty orthoclase, as well as by their size (one measured 4 mm. in length) are to be seen in the slice; they extinguish at over 20°, and are repeatedly twinned on the albite plan, except at the margin where the twinning disappears. If we now turn to the hand specimen there may be seen, in addition to the black specks produced by the ferromagnesian minerals, some small black spots up to 10 mm. in diameter, which have every appearance of being xenoliths. The high specific gravity of the rock (2·716) is evidently due to the included foreign material.

From this example we learn the possibility of distinguishing a heterogenetic from a homogenetic rock, in thin slices, even when unassisted by a knowledge of its relations in the field.

Augite Granophyre.—Specimen 4. Fragment taken from a thick dyke. In hand specimens this is a dark-coloured holocrystalline rock, speckled greenish grey and black, glistening on the fractured faces with numerous square and rectangular cleavage faces of felspar. In texture it is of medium coarseness, resembling a fine-grained dolerite. It weathers a light rusty brown, and the weathered face is pitted and dotted so as to suggest the presence of xenoliths of gabbro. The specific gravity is 2·738, determined, as in all cases cited in these descriptions, by a Walker's balance.

Under the microscope it is seen to consist of quartz in separate grains and occasional mosaics of dusty orthoclase, rarely micropegmatised with quartz, and of abundant xenocrysts of plagioclase and diallage and their alteration products, which include apatite, magnetite, and augite. The

whole slice has, as it were, a dirty appearance, owing to the dusty character of the orthoclase and the litter of decomposition products. The xenocrysts of bytownite generally retain their characteristic finely granular appearance over a central area, but the margins are frequently of glassy clearness; their growth is not uncommonly completed by orthoclase. The difference in the value of the angle of extinction between the centre and the margin is sometimes very great, in one case the centre extinguished almost symmetrically at 25° and the sides at 5°. The diallage is converted into clusters of colourless pyroxene granules, like the augite grains of basalt; associated with these clusters are numerous grains of magnetite. Sometimes the granules form a network, the interstices of which are filled with felspar; some of the granules are scattered, and may be seen lying isolated and immersed in crystals of orthoclase and grains of quartz. Some of the diallage has escaped this transformation, the only change which it has undergone being a loss of striation and the acquirement of a grass-green colour, accompanied by the excretion of magnetite.

Specimen 5.—Fragment from a fairly thick dyke. The hand specimen is a compact grey rock of a felsitic appearance, with a few glancing cleavage faces of felspar sparingly scattered through it. The specific gravity is 2·701. Under the microscope the groundmass is found to consist of a very fine-grained admixture of quartz and felspar, the grains, which are not very easy to individualise, varying from about 0·02 to 3·05 mm. in diameter, on an average, probably, about 0·025 mm. Scattered irregularly through this matrix are numerous grains of pyroxene, like those which were described as occurring in clusters in the preceding specimen, but here dispersed, though, in addition, clusters are also present, and xenocrysts of diallage altered in the same manner as previously described. The dispersed granules measure from about 0·005 to 0·05 mm. in diameter, on the average about 0·025 mm. Just as abundant as these granules, and of about the same size, are grains of magnetite which lie disseminated through the matrix. Xenocrysts of bytownite, often broken and penetrated by quartz, are fairly common; they look quite at home in the rock, and were its history unknown they would, I doubt not, have been taken for phenocrysts occurring in a remarkably basic augite granophyre, or perhaps quartz andesite, which

would have been regarded as of unusual interest when viewed in the light of modern theories of the differentiation of originally homogeneous magmas.

Specimen 6.—A fragment of a very large dyke. The hand specimen is a light grey or cream-coloured, completely crystalline rock, sparingly dotted with small green specks. The fractured surface presents so many cleavage faces of small crystals of felspar as to appear entirely made up of them.

Under the microscope it is seen to consist of grains of orthoclase and quartz, on an average about 1·3 mm. in diameter. The orthoclase manifests a great tendency to idiomorphic outlines; the quartz occupies the interstices as separate grains or mosaics; it is rich in liquid and vapour cavities. Green augite, evidently the product of pyroxenic xenocrysts, is scattered here and there; it is this mineral which is seen as dark green specks in the hand specimen. Excreted magnetite occurs, and altered xenocrysts of bytownite which has lost its dusty appearance, but contains alteration products.

It is interesting to observe, penetrating this specimen, a subsequently intruded granophyric dyke; this measures 15 mm. in width, and gives off more than one branch; one is only 0·2 mm. in width, another, as much as 2 mm., after curving outwards from its source, returns to it at a distance of 5 cm., thus enclosing a minute "horse" of the surrounding rock, which was evidently solid at the time of the injection. The substance of the later dykes is of much finer grain than that of the rock into which it is intruded; it consists of quartz and orthoclase in grains of about 0·2 mm. in diameter; the grains of quartz frequently present a lobate outline, and those lying near the surface of contact with the surrounding rock assume a singularly organic appearance, thrusting out pseudopodial processes, which are greatly elongated towards the surface of contact, which was plainly also a cooling surface; as these long processes are directed at right angles to the plane of contact they recall some of the structures of Foraminiferal tests.

Diallage Amphibole Augite Granophyre.—Specimen 7. A grey, fine-grained rock, glistening with the cleavage faces of minute felspar crystals,

weathering brownish white; xenoliths appear to be absent. Specific gravity, 2·712.

Under the microscope is seen a ground mass of felspar and quartz, usually in micropegmatitic intergrowths of various degrees of fineness; some of the micropegmatitic fringes to the felspar are of exquisite beauty. The quartz grains have a dusty appearance, as though filled with vapour cavities, but these are remarkably rare or even absent, and the effect is due to the inclusion of granules of a transparent mineral, which is either felspar or a derivative of that mineral. Scattered somewhat abundantly through the rock are xenocrysts of diallage and their alteration products, such as magnetite, almost colourless augite, and green amphibole, which is interpenetrated by quartz, and usually occurs as a fringe of various breadth surrounding the xenocrysts. This amphibole extinguishes at 9°, and is only faintly pleochroic.

Corroded xenocrysts of plagioclase are numerous; they have frequently served as a nucleus for the deposition of orthoclase which has completed their growth.

The abundance of basic material in this rock is suggested by its high specific gravity; at the same time it affords the clearest evidence of its dual origin. To the single-minded differentiationist it might appear as an admirable link between the extreme acid and basic members of a petrological series; the evidence, both of the microscope and the field, affords a simpler explanation, by showing that a mixture of extremes has taken place with a product of mean composition as the result. The observer is frequently reminded, in this study of the evolution of rocks, of the history of discovery in the affiliation of animals. How often has not some animal form been described as combining the character of two widely different groups, only to be subsequently explained away as an accidental intermingling of two separate individuals? Thus, on one occasion, thread-cells (cnidoblasts) were described as occurring in a species of sponge, which thus became an important link between the sponges generally and the cœlenterata; the discovery excited great interest till it was found that the thread-cells were not proper to the organism, but had been accidentally introduced from without.

The question naturally suggests itself, whether the quartz grains in the "quartz-basalts" of Diller and Iddings may not after all be derivative; they admittedly behave like xenocrysts, and the fact that associated quartzless basalts possess a similar chemical composition to those containing quartz may be explained on the assumption that in the former complete absorption of the quartz has taken place.

XENOLITHS IN THE GRANITE OF NEWRY.

The basic patches included in the palæozoic granite of Newry have already been described by Mr. J. A. Phillips, in a valuable communication, "On Concretionary Patches and Fragments of other Rocks contained in Granite."* Some of the inclusions are clearly shown to be xenoliths of the adjacent mica-schist; others, distinguished by their "ovoid" form, are supposed to be "concretionary." The general subject has also been treated by Mr. Teall, who suggests "that somehow or other these patches are the result of differentiation accompanying the crystallization of the original magma."†

A fine specimen of a rounded, or ovoid basic patch or "pocket," as the quarry-men call it, is preserved in the collection of the Geological Museum, Trinity College; it is part of a rounded nodule, measuring about 3″ by $1\frac{1}{2}$″ by 1″, completely soldered to the white granite, in which it lies embedded. So close is the union between the two rocks that three planes of fracture, the front, back, and one side of the hand specimen, have passed through them without starting the slightest tendency to separation; the two cohere like one rock. At the same time, owing to their marked difference in colour, there is no difficulty in determining where one begins and the other ends.

On one of the fractured surfaces of the xenolith long black crystals, looking like labradorite, are very conspicuous, giving it very much the appearance of some of the gabbro of Barnavave; this resemblance, though deceptive, led me to investigate it more closely. A thin slice shows abundant brown biotite, highly dichroic and orientated in one direction, so as to

* "Quarterly Journal, Geological Society," vol. xxxvi., p. 16, 1880.

† Teall, "British Petrography," p. 311, 1888.

produce the semblance of foliation, and a good deal of green hornblende in large, much corroded crystals containing felspar and quartz; it extinguishes at 22°, and is highly pleochroic,

α, honey yellow; β, olive-green; γ, dark bluish-green.

A portion of one of the black crystals cleaved from the rock with a penknife proved to be this mineral. Plagioclase felspar fills up the interstices, occasionally presenting idiomorphic outlines; it frequently includes numerous small crystals of hornblende. The bands due to twinning on the albite plan are only moderately coarse, and zonal structure is common. Excreted magnetite is fairly abundant, and there is a good deal of apatite, with here and there a crystal of zircon.

The powdered rock placed in a diffusion column gave no perceptible orthoclase, but plagioclase felspar was abundantly present, extending from 2·63 down to 2·75. A dense zone at 2·65 was found to consist of quartz and felspar. Biotite floated with a specific gravity of 3·03, and was followed by hornblende and apatite, with a specific gravity of 3·187. Sphene, both colourless and pinkish (ferriferous), together with magnetite and zircon, were found at the bottom of the column.

The heaviest felspar was found to give a strong sodium reaction to the flame test, but no trace of potassium. A qualitative analysis showed the presence of a good deal of lime: hence it is clearly a soda-lime felspar.

The flakes of highest specific gravity were found to contain inclusions of hornblende and apatite; those of specific gravity 2·65–2·712 consist for the most part of granular cores, having a cryptocrystalline effect on polarised light; but to these cores a clear, fresh margin is sometimes added. It often extinguishes approximately parallel, and may then be safely regarded as andesine. Sometimes, however, symmetrical extractions of from 8° to 16° may be observed, indicating the presence of more basic plagioclase.

The surrounding granite contains the same minerals as the xenolith, and in addition a good deal of orthoclase of specific gravity 2·56. The specific gravity of the biotite and hornblende in the granite is practically identical with that of these minerals in the xenolith.

From its rounded form and mineral constitution this nodule would be included in Mr. Phillips' classification in the category of "concretions," but the observations we have recorded agree in suggesting for it a xenolithic nature. Mr. Phillips has himself suggested that the biotite in these inclusions may have been produced from hornblende; and we have already seen how both biotite and hornblende may arise from the action of granite on the diallage of gabbro; and that this is the direction in which we must seek their origin in the case before us is suggested by the nature of the associated felspar, which belongs exclusively to the soda-lime series. A fragment of gabbro caught up by the granite might be presumed, from the facts exposed at Barnavave, to produce just such an inclusion as that under consideration; that it is not a segregation product is clearly shown by the suddenness of the transition between it and surrounding granite.

If it be admitted that this inclusion is truly a xenolith of gabbro, a very important conclusion follows; for, looked at simply as a mineral complex, it cannot be refused its place in classification as a quartz biotite diorite, and thus we have an example of the production of this kind of plutonic rock, not by differentiation, but by the interaction of a granitic magma and solid gabbro. The facts will be no whit less interesting should it, as may be possible, prove to be an altered xenolith of the adjacent mica schist.

General Conclusions.

In the hill-side of Barnavave we find laid bare to observation the results produced by the action of molten material on the walls which hem it in. These results are, on the one hand, the injection of the gabbro which formed the sides of the cistern by granophyric material, and on the other the absorption of the gabbro by the granophyre, which thus became converted into several very different varieties of rock.

These effects have been studied in comparatively narrow dykes, which do not seem to have consolidated at any very great depth below the surface of the ground. But the significance of the phenomena is thus rendered all the more striking, for, if the thin streams of igneous rock which gave rise to the dykes were capable of producing such marked effects as we have

observed, how vastly greater might we expect to find the action of molten material to be in the case of deeply-seated igneous seas. In the thin dykes the action of the igneous material has been arrested by cooling before its completion, so that we are now able to study the effects in all their stages. Far otherwise is it with the subterranean molten seas. In these the absorption and transformation of the containing walls is more thorough and complete; only the final products of digestion remain; and these, when they are ejected at the surface of the earth, offer but slight suggestion of their complex origin. Yet when the plutonic masses have consolidated, and are revealed by denudation, some signs of the absorption which has taken place may still be traced, for no one can contemplate the great flakes of the surrounding country which lie isolated and immersed in granite tracts like that of the Leinster mountains, without recognising in them the few surviving remains of a far greater quantity of material which has been dissolved away. Such xenoliths as those which occur at Newry are indications of a similar absorbent action.

One advantage the dykes do certainly possess over the subterranean masses: their mass is small compared to the surface of the surrounding walls. The effect of the latter in bringing about modification by admixture is therefore greater; it is also possible that nearer the surface the molten matter is more highly charged with water, and thus endowed with greater chemical activity.

It will be judicious to refrain from further generalization from observations founded on a single area, but the subject naturally suggests some reflections on the difficult question of the "differentiation of originally homogeneous igneous magmas."

One of the districts in which the differentiation of igneous rocks has been best studied is that of Christiania, which has been rendered famous by the investigations of Scandinavian geologists, but more especially by the classic works of Brögger.

Ancient as the igneous rocks of this district are, ranging from the Devonian upwards, they are still young when compared to the date of the first formation of a permanent crust to the earth; but immediately on the formation of such a crust a differentiation must have commenced to take

place in the residual fluid matter below it. Hence, if we are precluded from deriving ejected igneous material from a zone below the earth's crust, and are bound, as for some reason most Geologists seem to imagine, to find it a halting-place in some inter-crustal cistern; yet all the same, these cisterns must be supplied, not from a homogeneous, but from an already differentiated magma; and unless the in-gushes of igneous matter become thoroughly well mixed during their journey upwards, we shall not have a homogeneous magma from which to derive the successively erupted rocks. An original homogeneous magma does not seem to be an existence discovered by observation; it is rather of the nature of a postulate, which nothing in the nature of the human mind compels us to grant, and which to my mind is opposed to the general probabilities of the subject.

That the differentiation, which from very early times affected molten material below the earth's crust, should also occur in magma basins lying within it, is a view to which great probability attaches; but no attempt hitherto made to connect such a differentiation with the order, if any one order exists, in which igneous rocks are extruded at the earth's surface, appears to me to have achieved complete success. And this for two reasons: the first, that no regular order of succession can yet be said to have been clearly established; the second, that no invariable order is maintained in the differentiation of minerals from a parent magma; tendencies to a definite order of crystallization, no doubt, have been exposed, but always with exceptions.

A third reason for failure might have been added, viz. that even if a constant order had been determined both for the eruption and the differentiation of igneous products, the rationale of their connexion has not hitherto been unfolded.

This clearly appears from the history of the subject; for, on the earliest formulated view, the eruption of igneous rocks in any district was supposed to commence with the most acid, those of intermediate composition followed, and the basic concluded the series. This was very naturally regarded as in obvious consistence with the order in which differentiated products would arrange themselves under the action of gravity, and from such an arrangement the order of eruption would naturally follow. With the progress

of inquiry this order of eruption was not found to obtain universally, nor even generally, and, as a deduction from von Richthofen's observations, a new order was evolved, in this case from the intermediate rocks as the first erupted, through the acidic next, and the basic, as before, last of all. This, again, was claimed as in complete accordance with the order of events which might be supposed to take place in the magma basin, since rocks of intermediate composition might be regarded as representing the original homogeneous magma from which were subsequently evolved the extreme acid and basic varieties; these would separate into an upper lighter and lower heavier layer under the action of gravity, and be erupted from above downwards.

Lately, from the observations of Brögger, Iddings, and Teall,* this order is shown certainly not to be universal, possibly not general, in its application; and a third order has been proposed as truly representing the facts; in this the order of eruption is as follows:—first, basic rocks; second, intermediate; third, acidic; fourth and last, basic. This order may be regarded as established for the district of Christiania, and may prove to obtain elsewhere.

A little surprise may be pardoned on finding that this succession also has been welcomed as exactly meeting the requirements of the differentiation hypothesis. To a plain person the history of inquiry would seem to teach that the order of eruption does not necessarily stand in any direct connexion with the order of differentiation.

If the explanation of connexion between the order of differentiation and the order of eruption proposed by Brögger, in the case of the Christiania district, be examined in detail, the difficulties of the question seem to increase. For it is supposed that near the cooling surface, which is said to lie near the roof of the magma basin, the more basic material will tend to accumulate under the action of Soret's law, and that thus the higher layers of the magma will be separated as a more basic material from the lower. The higher layers are supposed to be the

* "On the Plutonic Rocks of Garabal Hill and Meal Breac," by J. R. Daykins and J. J. H. Teall, Quarterly Journal, Geological Society, vol. xlviii., p. 104, 1892.

first to be extruded, and thus the earliest eruptions of the district consist of basic rocks.*

It is not without mental discomfort that one can contemplate the heavier basic layers floating on the lighter acid ones, nor does any valid reason appear why the laws of gravity should be suspended to meet the exigencies of an hypothesis.

Given a magma sufficiently fluid to allow of such molecular movements as Soret's law presupposes, the differentiation resulting would produce an eminently unstable distribution of the magmatic layers; and one may predict, with a considerable amount of probability, that so soon as the heavier material appeared at the surface, it would at once commence to descend towards the bottom of the basin, while lighter and more acidic material would replace it, the final result would be an arrangement of the magmatic layers in the order of their density. This has been partly recognised by Brögger, who endeavours to account for the basic character of the final eruptions in the area on the supposition that, during differentiation, some of the basic material would fall to the bottom of the cistern; it is singular, however, that the fatal nature of this admission, as affecting the other portion of his theory should not have been recognized by Brögger.

If it really be necessary to have recourse to a magma basin in explaining the order of eruption of igneous products, the distribution of the layers brought about by the differentiation of its contents, will probably be determined by their specific gravity, and they will be characterized by an increase in density from above downwards. Such a distribution once established, the order of the emission of the different layers will depend on the manner in which the magma basin is tapped. Should a channel of communication be opened from the bottom upwards, the basic rocks will be drawn off first; and subsequent outflows will exhibit increasing acidity; and in such a case, if the channel only approach without actually reaching the lowest level in the basin, then it is quite possible that the final eruptions would repeat the basic character of the first.

* Brögger, "Die Mineralien der Syenitpegmatitgänge der Südnorwegischen Augit- und Nephelin-syenite." Zeits. f. Kryst. und Mineralogie, Bd. xvi., p. 83, 1890.

Several crudities, however, may be detected in such an explanation, for it postulates first a completely filled cistern, and next an almost completed differentiation of its contents as a preliminary to igneous manifestations at the surface of the ground. The question as to how the basin might have originated, and in what manner it became filled, force themselves upon the attention; and Uniformitarian and Evolutionist alike will be agreed in asserting that neither the formation nor the filling up of the basin would be likely to occur instantaneously; both processes were, in all probability, gradual and slow, possibly even taking place *pari passu* with the outpouring of fluid material at the surface. But from this reflection we are inevitably led to another: whence do the contents of the cistern derive their origin? Try to evade it as we may, we are at last led to the still heated interior of the earth. But directly we thus relinquish the unphilosophical attitude of regarding cistern and its contents as ultimate facts, we are brought into face with the difficulty that the heated material of the interior is already, in all probability, in a high state of differentiation; and thus the old ideas of Durocher reassert themselves in another form.

Though differentiated, these interior layers are at present quite possibly solid, but they may reassume a state of fluidity in more than one way—a relief of pressure, in consequence of folding, was at one time suggested by Mr. Fisher—an increase in pressure in certain directions leading to a solid flow, and internal friction might be suggested as an alternative. But if we inquire whether, of two layers, an acid and a basic one would earlier acquire the liquid state, we shall find that it would be a matter of conditions; but the probabilities are on the whole in favour of the basic layer, for not only does it melt at a considerable lower temperature than the acidic, but it also probably occupies a deeper position within or below the earth's crust, and consequently may be presumed to possess a higher initial temperature. Thus it would require only a relatively slight relief of pressure, or only a slight difference of pressure, to reconvert it into a molten magma. Following upon the escape of this at the surface, the acid layers would become melted either by a continuation of the change in pressure or by sinking downwards into regions of higher temperature *pari passu* with the rise of the basic material upwards.

It will not be necessary to press this speculation further at present, but it would seem obvious that much more attention must be given to the investigation of the details of the now prevalent differentiation hypothesis before it can be regarded as established on a firm basis.

REFERENCES.

(1) 1843. Griffith, Sir R., Journ. Geol. Soc. Dub., p. 113.

(2) 1856. Haughton, Rev. S., "Experimental Researches on the Granites of Ireland," Quart. Journ. Geol. Soc., vol. xii., p. 171.

(3) 1858. *Ib.*, *op. cit.*, vol. xiv., p. 300.

(4) 1876. *Id.*, "On the Trap Dykes of the District of Mourne," Journ. Roy. Geol. Soc. Ireland, vol. xiv., p. 91.

(5) 1878. Traill, W. A., "Memoir to accompany Part of the Sheets 60 and 71 of the Geological Survey of Ireland."

(6) —— Lasaulx, A. von, "Olivingabbro von den Carlingford Mountains," "Tschermak Min. u. Petr. Mitth.," vol. i., p. 426.

(7) 1888. Teall, J. J. H., "British Petrography," p. 275.

The literature of the general subject of foreign inclusions in igneous rocks, which has grown rapidly during the last ten years, need not be given here, since a full summary will be found in Zirkel's last great work, "Lehrbuch der Petrographie," Bd. I. Leipzig, 1893. The sections, "Contact-metamorphismus an eingeschlossen Bruckstücken," p. 593, and "Specielle Vorgänge bei der Gesteinsverfestigung," p. 711, may be especially referred to.

EXPLANATION OF PLATE XXVI.

Figure

1. A dyke of granophyre, recognisable by its white colour, intruded into gabbro, on the northern side of Barnavave. The dark spots seen in the dyke represent included fragments of gabbro. The scale is given by the hammer (14 inches in length) to the left of the dyke.

2. Breccia of gabbro injected by granophyre. This is a portion of the view given in fig. 5.

3. Dykes of granophyre passing into a plexus inclosing a gabbro breccia, like that shown in the proceding figure.

4. Part of a thin slice of gabbro from Barnavave, including in the middle two crystals of diallage, with thread-like intergrowths, cut longitudinally. (See figure, p. 485.) (× 18.)

5. Breccia of gabbro injected with granophyre. The figure in the lower left-hand corner gives the scale.

6. Section of diallage in gabbro, with thread-like intergrowths, cut across traversely. (× 34).

7. Intersecting groups of lamellar dykes of granophyre in gabbro.

8. A xenocryst of diallage in granophyre, converted at the margins into green amphibole. The diallage is distinguished by its lamellar striation. (× 60).

9. A plexus of granophyre dykes in gabbro.

EXPLANATION OF PLATE XXVII.

Figure

10. A xenocryst of bytownite (containing evenly disseminated fine opaque dust, twinned, and extinguishing symmetrically at 30°), the growth of which has been completed by a less basic plagioclase (clear, free from dust, and extinguishing symmetrically at 12°). (× 30.)

11. A xenocryst of diallage in augite, biotite, granophyre, with adjacent grains of augite and flakes of biotite, which have been derived from it. (× 40.)

12. A cluster of crystal grains of augite, remnants of a xenocryst of diallage. (× 40.)

13. A transformed crystal of diallage, situated in gabbro, close to its junction with a granophyre dyke. The greater part is uralitised, but the central area retains its augitic character. (× 50.)

14. A xenocryst of green amphibole in granophyre, resulting from the alteration of diallage, of which a residue persists as the core. (× 42.)

15. A xenocryst of bytownite, broken and corroded, surrounded and penetrated by orthoclase. (× 14.)

16. A glomerulus of magnetite, augite, and quartz, the alteration products of a diallage xenocryst. (× 43.)

17. A thin slice of gabbro, injected with granophyre. A thin dyke of granophyre is seen at the lower left-hand corner. The white stellate patch near the middle of the slice represents a druse filled up with granophyre. (Natural size.)

18. Part of a thin slice of coarse granophyre, and a small dyke of finer granophyre injected into it. Along the junction which runs through the middle of the figure, the quartz of the finer granophyre is seen extending in apophyses, which are directed at right angles to the surface of the coarser granophyre. (× 37.)

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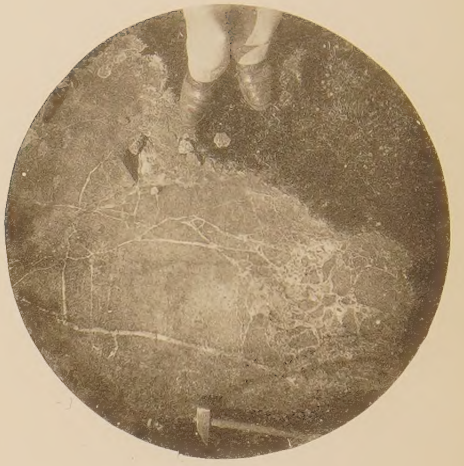

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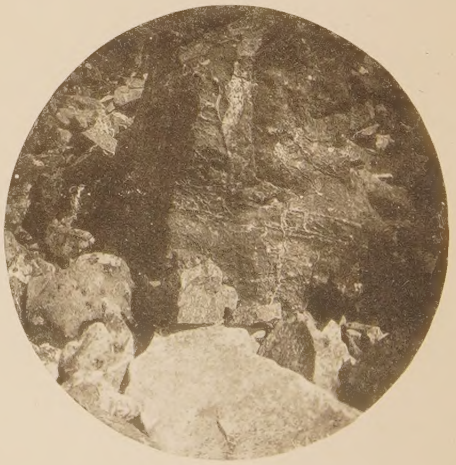

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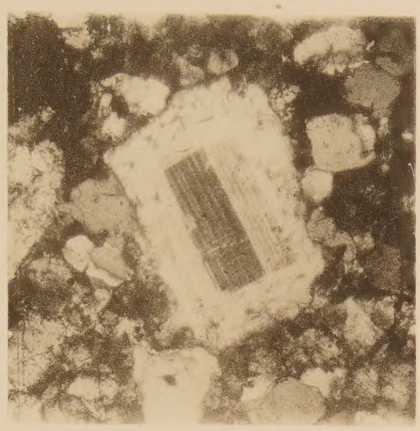

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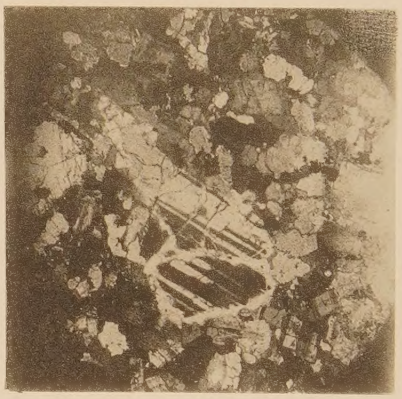

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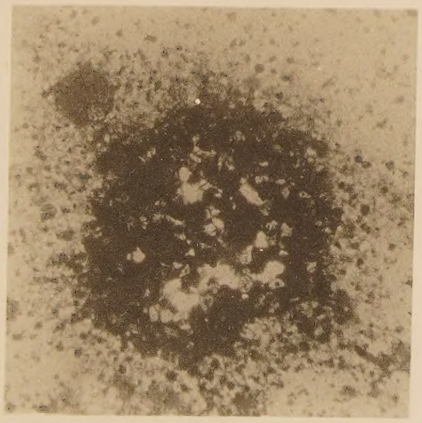

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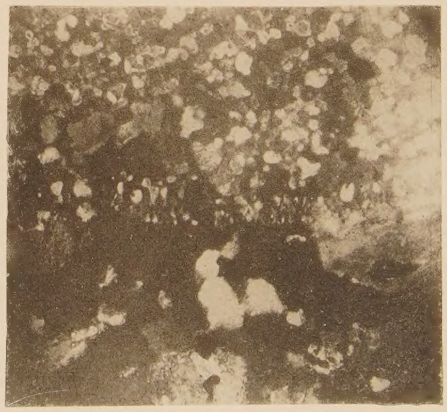

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